balance in saturated solutions at temperatures not far removed from 0° between 0° and 25°.

In conclusion, it may be desirable again to emphasise our view that the phenomena of competitive dissolution are of a very complex character. It would seem probable, however, that the precipitation of salts from solution is mainly due to what may be termed collectively "*dehydration changes*," conditioned not only by the direct withdrawal of water from the solution by the precipitant but, in the case of neutral solvents particularly, also by the agency of the increased proportion of hydrone molecules brought into being in the water by the mechanical interposition of the molecules of the precipitant.

We desire to express our particular thanks to Mr. D. R. Keller, who with unwearied perseverance and care has carried out much of the practical work described in this communication, thereby rendering us invaluable assistance.

The Distribution of Velocity in the β-Rays from a Radioactive Substance.

By J. A. Gray, B.Sc., 1851 Exhibition Scholar, University of Melbourne.

(Communicated by Prof. E. Rutherford, F.R.S. Received May 6,—Read June 9, 1910.)

[Plate 1.]

It is well known that the α-particles emitted from a thin film of radioactive matter of one kind are initially projected at an identical speed. No definite evidence, however, has yet been obtained whether a similar result holds for a substance which emits β-particles in its transformation. Hahn has found by the electrical method that β-rays from a simple radioactive substance are absorbed very nearly according to an exponential law, and has utilised this property to decide whether the source of β-rays consists of one or more products emitting β-particles. This method, in the hands of Hahn and Meitner, has proved very fruitful in bringing to light new and unsuspected β-ray products.* In addition, it has been assumed by many

* Hahn and Meitner, 'Phys. Zeit.,' 1909, p. 697.

writers that the exponential law of absorption is a proof that the rays are homogeneous, *i.e.*, that the β-particles are emitted initially at an identical speed, and, further, that the velocity of the β-particles does not change appreciably in traversing matter.

W. Wilson* has attacked this question from another direction. Using radium emanation, he has sorted out the rays from the active deposit by means of a magnetic field, and obtained rays which, if not homogeneous, only cover a small range in velocities. Testing these rays by means of an electroscope, he found that when the ionisation was plotted against the thickness of absorbing matter, the curve obtained was not exponential, but very nearly a straight line. This indicated that the absorption of nearly homogeneous rays was not a constant, but increased with the thickness of matter traversed. Such a result can only be explained by a loss of velocity in β-rays as they pass through matter. It shows also that an exponential law of absorption does not signify homogeneous β-rays, but rather rays with a particular distribution of velocities.

This point of view has been a matter of discussion between Hahn and Meitner† and Wilson,‡ and the former in their paper supported the view that an exponential law of absorption is a proof that the β-particles are homogeneous, and do not decrease appreciably in velocity in passing through matter. It has been the object of the experiments described in this paper to obtain independent evidence on this important question by deflecting the β-rays from some radioactive substance in a magnetic field.

The photographic method was used, the detection of one or more sets of homogeneous β-rays being attempted. Radium emanation was the substance first used. The emanation produces RaB and RaC, both β-ray products, and when radioactive equilibrium is established we have a source of β-radiation which is approximately constant during the course of a few hours. The emanation was contained in a narrow thin-walled tube, similar to the tubes used by Rutherford and Royds when they proved that the α-particles were positively charged atoms of helium. The thickness of the tubes was such that it was equivalent to about 3·5 cm. of air, so that the α-particles from RaA and the emanation could escape. The tubes were made thin, so that there should be as little absorption as possible of the β-rays affecting the photographic film used, but enough thin black paper was placed over the tube to protect the film from the α-particles and the phosphorescence caused by them. Thus the β-rays had very little matter to pass through, so that if there were sets of homogeneous rays in the β-radiation, these should have been detected, even if the β-rays did change slightly in velocity in passing through matter.

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* Wilson, 'Roy. Soc. Proc.,' 1909, A, vol. 82, p. 612.

† Hahn and Meitner, 'Phys. Zeit.,' 1909, p. 948.

‡ Wilson, 'Phys. Zeit.,' 1910, p. 101.

The capillary tubing was joined to a vessel containing purified emanation, and the latter was pushed into the thin tube by mercury. The capillary tube was sealed off and placed in a lead tube fixed to the brass plate LM (Plate 1, fig. 1).

Fig. 2 represents the experimental arrangements adopted, the section being perpendicular to the tube in fig. 1. The apparatus was in the form of a box 12·5 cm. cube. The active material A was parallel to a slit S, 5 mm. wide, formed by two lead plates 1·3 mm. thick. A photographic film P could be fixed across the slit by means of the holder H. This holder fitted tightly into an opening in the box, which could be made air-tight. By means of the tube T connection could be made with a Fleuss pump in order to evacuate the box. The box was placed between the poles of an electromagnet, the magnetic field being parallel to the slit. When the film was placed in position, the box was evacuated and the photograph taken.

Several photographs were taken, but there was no sign of a set or sets of homogenous β-rays. This can be seen from fig. 3. The narrow band is caused by the undeflected β-rays, in absence of a magnetic field. The other band, or magnetic spectrum, as it may be called, shows no sign of bands, the spectrum being quite continuous. The experiments, therefore, gave no evidence that there were sets of homogenous β-rays emitted by RaB and RaC. The result, however, is confused by the fact that there are several β-ray products, and a more definite result would be obtained if we examined a substance in which there is only one element emitting β-rays. This was done by using RaE.*

As many experimenters have shown, the absorption of the β-rays of RaE is very nearly exponential over a wide range, and consequently, by taking photographs as above, we can easily see whether an exponential law of absorption signifies homogenous β-rays or not. Some carefully purified RaD, which subsequent γ-ray measurements showed to be practically free from radium, was placed in a narrow groove in an aluminium plate. The groove was 0·4 mm. wide and deep and 1·3 cm. long. RaD, on disintegration, forms RaE and, when radioactive equilibrium is established, we have a practically constant source of β-radiation. A thick layer was necessary in order to obtain photographs in a reasonable time, but as, on examination, the rays used were absorbed exponentially until the intensity was about 10 per cent. of the original intensity, this did not affect the result.

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* The experiments of Antonoff ('Phil. Mag.,' vol. 19, p. 825, June, 1910) show that there is only one radioactive product between RaD and RaF, viz., RaE, which emits β-rays absorbed according to an exponential law. Formerly, two products, RaE_1 and RaE_2, were supposed to exist.

The absorption was tested in two ways. In the first the active material was placed about 10 cm. below a small electroscope and an absorption curve taken. In the other a small proportion of the rays were allowed to pass through a small hole in a lead screen and the absorption curve taken, using an ordinary β-ray electroscope. The absorption in both cases was practically exponential over the greater portion of the range, being somewhat greater after the intensity had been diminished to 10 per cent. Curve A, fig. 4, in which the logarithm of the activity is plotted against the number of absorbing sheets, is practically a straight line. The average thickness of a sheet was 0·0848 mm., the value of the absorption coefficient obtained being $\lambda = 43{\cdot}1$ cm.$^{-1}$. The tube A of fig. 1 was replaced by the aluminium plate, and the slit S was formed by two graphite plates 1·4 mm. thick, and was about 0·4 mm. wide.

Several photographs were taken, and figs. 5, 6, and 7 show some of them. In the case of fig. 5 there was atmospheric pressure in the box and no magnetic field. The photograph shows the scattering of the β-rays in air, and why it was necessary to work with the air at very low pressure. In fig. 6, the box was evacuated and there was no field, the exposure lasting 20 hours. In fig. 7, the box was also evacuated, but there was a magnetic field of 256 Gauss. There were several photographs taken in this way, all with similar results. In one of them the β-rays had first to pass through 0·12 mm. of aluminium.

The exposure for fig. 7 was 36 hours. The narrow band in this figure is mainly due to phosphorescence at the active material, and serves as a central band to determine the ranges of velocity of the β-rays. The other band, or magnetic spectrum, on comparison with the band in fig. 6, shows at once that the β-rays from the active material are by no means homogeneous, but that their velocities cover a wide range. It can be seen in this band that the intensity fades away on each side of the maximum, the limits being difficult to fix with certainty.

Knowing AS = 1·49 cm., SP = 1·61 cm., we can calculate the radius of curvature R of the path of the β-rays in a magnetic field H. If d be the deflection measured on the film,

$$R = \frac{SP\,(AS + SP)}{2d} \text{ approx.}$$

Then, if e/m be the ratio of charge to mass of β-rays of speed v, e/m_0

the same ratio for very slow speeds, c the velocity of light, we can calculate the velocities of the rays from the equations

$$\frac{mv}{e} = \mathrm{HR},$$

$$\frac{e}{m} = \frac{e}{m_0}\sqrt{1-\frac{v^2}{c^2}} \text{ (Lorentz's equation),}$$

e/m_0 being taken $= 1{\cdot}74 \times 10^7$ E.M.U.

In this way it was found that mv/e for the rays had all values between 3750 Gauss cm. and 1000 Gauss cm., or v between $2{\cdot}70 \times 10^{10}$ cm. per second and $1{\cdot}47 \times 10^{10}$ cm. per second.

It is scarcely possible to fix with certainty the velocity for which there is the maximum number of β-particles. An approximate determination has been made by measuring the distance between centre of narrow band and position of maximum intensity on the film magnetic spectrum and then calculating HR. The value found for HR was 2300 Gauss cm., giving a velocity of $2{\cdot}4 \times 10^{10}$ cm. per second. This result agrees fairly well with that of Schmidt,* who found HR = 2178 Gauss cm. by the electrical method.

From the above, we see that β-rays, which are very nearly absorbed according to an exponential law, are by no means homogeneous. Now, if we have a mixture of β-rays of different speeds and take an absorption curve, the slower rays will be cut down more in proportion than the faster rays, so that the absorption coefficient should decrease as the rays traverse matter, provided there is no change in velocity. If the absorption coefficient is to remain the same or increase, there must be a loss in velocity of β-rays in traversing matter.

The above experiments do not prove directly that the β-rays from RaE are not initially expelled at an identical speed, for it is possible that the β-rays coming from the lower layers of the active material may be so changed in velocity that an exponential law of absorption results from the mixture. However, in this case we could not expect that the rays from a thin film of RaE would be absorbed exponentially, and also we should expect a different coefficient of absorption for the thin layer. An absorption curve was taken of the β-rays from a thin film of the material used in taking the photographs. In this film the absorption of the rays in the active material is very small, and care was taken that very little secondary β-radiation entered the electroscope, yet the rays from the RaE are absorbed exponentially. The result is shown in curve B, fig. 4, the absorption coefficient being 42 cm.$^{-1}$. It is therefore practically certain that the β-rays from RaE are initially expelled,

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* H. W. Schmidt, 'Phys. Zeit.,' 1909, p. 372.

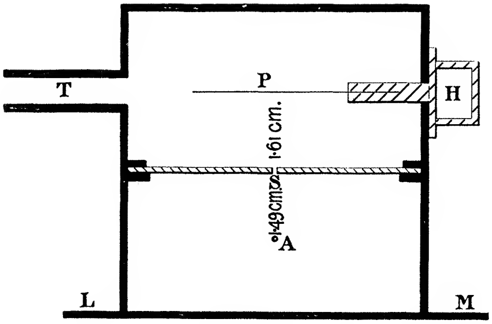

Fig. 2.

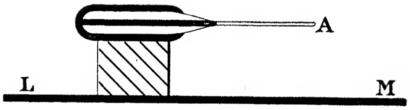

Fig. 1.

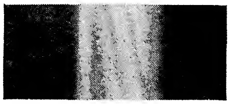

Fig. 3.

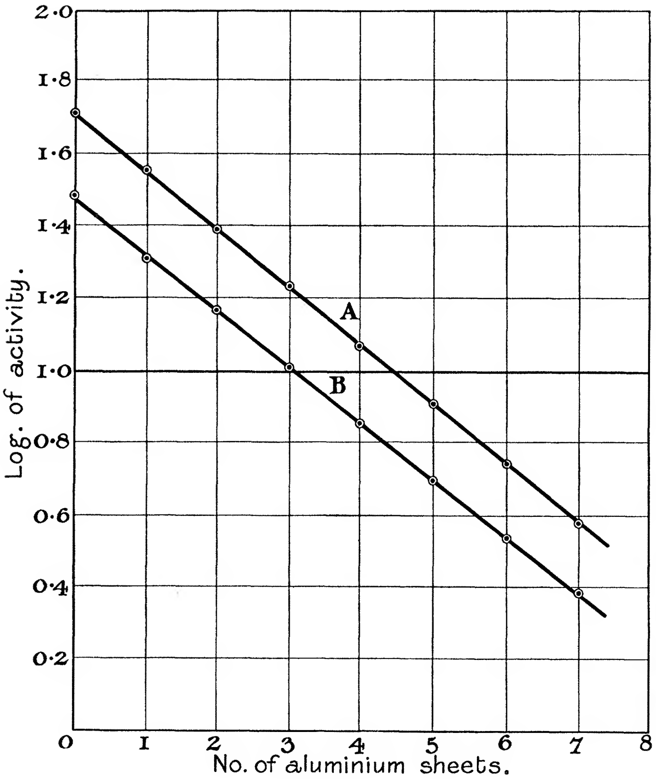

Fig. 4.

Fig. 5.

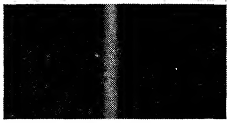

Fig. 6.

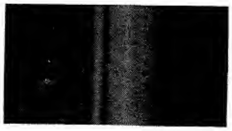

Fig. 7.

not at an identical speed, but with widely different velocities. The experiments with radium emanation gave similar evidence with respect to the β-rays from RaB and RaC.

Summing up the experiments which, as we have seen, confirm Wilson's results, we may say that—

1. β-rays, which are absorbed according to an exponential law, are not homogeneous.
2. β-rays must fall in velocity in traversing matter, for, if not, the absorption coefficient of any mixture of rays would decrease as the rays passed through matter.

In conclusion, I wish to express my thanks to Prof. Rutherford for suggesting these experiments and for his advice and help during their progress, and also to Dr. Boltwood, who separated and purified the sample of radium D employed in these experiments.

The Decrease of Velocity of the β-Particles on Passing through Matter.

By William Wilson, M.Sc., Hon. Research Fellow of the University of Manchester.

(Communicated by Prof. E. Rutherford, F.R.S. Received May 6,—Read June 9, 1910.)

Introduction.

In a previous paper[*] it was shown that the absorption of homogeneous β-rays by matter when determined by the ionisation method does not take place according to an exponential law, as had previously been assumed, but according to a law which is practically linear.

This means that the absorption coefficient[†] of the rays becomes greater the further the rays penetrate the absorbing medium, and since the absorption coefficient increases with decreasing velocity of the β-rays it suggests that the rays are slowed down on passing through matter.

Some experiments were described[‡] which fully confirm this view.

[*] Wilson, 'Roy. Soc. Proc.,' A, vol. 82, 1909.

[†] If β rays of intensity I fall on a layer of matter of thickness dx, the intensity is decreased by $\lambda I\,dx$, and λ is called the absorption coefficient of the rays. For an exponential law of absorption λ is constant.

[‡] *Loc. cit.*, p. 625.

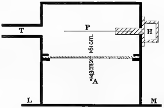

Fig. 2.

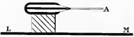

Fig. 1.

Fig. 3.

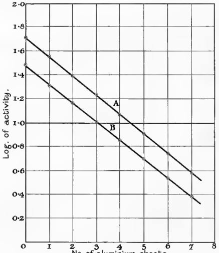

Fig. 4.

Fig. 5.

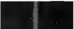

Fig. 6.

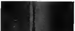

Fig. 7.